The Stream of Life.[1]

By PROF. ARTHUR DENDY, F.R.S.

ALL typical organisms—animal or vegetable—are composed of cells; minute nucleated masses of protoplasm, existing either singly or in many-celled aggregates. These cells are capable of reproducing themselves by a process of division, and each of the higher organisms, with certain negligible exceptions, starts its life in the condition of a single cell which we call an egg or ovum, or, to use a more general term, a germ-cell.

Whatever may have happened in the far-distant past, at the present day, so far as we can see, every living thing is the product of some pre-existing living thing, the relation of parent and child holds good throughout the whole organic world, and when we come to analyse this relationship from the biological point of view we find that it is always essentially based upon cell-division. Leaving out of account, as we may legitimately do for our present purposes, the stages of protoplasmic evolution that precede the appearance of the nucleated cell, we may say that the cell is the unit of organic structure, that all organisms are built up of such units in somewhat the same way as a house is built up of bricks, except that the process of building in the living organism is one of cell-growth and cell-multiplication, while the bricks of a house are brought together and combined into a building by some external agency. This fundamental conception of organic growth leads to the still more fundamental conception of living matter as a continuous stream of protoplasm, starting with the first appearance of life on the earth and continuing to the present day with undiminished vigour; but it is a stream which in the process of time constantly branches out in new directions, giving rise ever to more complex and more diversified types of plants and animals. It is the stream of life. To make use of a more familiar metaphor, the whole organic world may be compared to a great tree, the roots of which are dead and buried in the past, and the leaves and flowers of which, individualised and endlessly diversified, are represented by the living plants and animals of to-day.

Let us now examine a little more closely the means by which successive generations of organisms, parents and offspring, are linked together. We have to ask ourselves the question: Why do all except the simplest organisms reproduce themselves by means of eggs, instead of simply dividing up into equivalent parts? In other words, why does every plant and animal of a new generation have to go back to the beginning and start its life as a single cell? We may approach this question by considering for a moment a once familiar domestic operation—the baking of bread. You have no doubt sometimes heard the expression "half-baked" applied to human beings, which shows that the analogy I propose to make use of is not altogether new. If we want to increase the number of our loaves it is no good simply cutting them in halves. We must go back to the dough and out of it fashion new loaves. The dough, properly prepared, contains all the ingredients necessary for bread-making and is capable of developing into loaves when subjected to the right treatment. When once it has developed into a loaf, however, it cannot be turned back again into dough.

So it is also with the living organism. When once the protoplasm of the egg, or germ-plasm, as it is technically termed, has developed into the mature tissues and organs of the adult body, it cannot, usually at any rate, be turned back again into germ-plasm; it continues to live for a time, but the stress and strain of life gradually exhaust its vitality; for a time, tissues and organs may be renewed, but ultimately some essential part of the mechanism of the body is worn out beyond the possibility of repair, and the death of the entire organism inevitably follows.

What provision, then, is made for the next generation—who mixes the next batch of dough? Here I am afraid our analogy breaks down, and it breaks down just because the germ-plasm, unlike the dough, is a living substance capable of increasing itself indefinitely by growth and multiplication. What happens is typically this—a part of the original germ-plasm of each generation is set aside, taking no share in the development of the body, but remaining in the condition of comparatively undifferentiated protoplasm, while continuing to increase and subdivide into germ-cells. It thus appears that the old idea that the hen produces the egg is scarcely correct—it seems that the egg produces the hen and at the same time more eggs, which are accidentally, as it were, included in the body of the hen. The constant succession of germ-cells, each produced by division of a parent cell, constitutes the only really continuous stream of living protoplasm. The bodies of individual plants and animals, developing from the germ-cells, may be compared to local and temporary overflows from the stream, which sooner or later dry up and disappear, or, in other words, die. This is Weismann's well-known doctrine of the "continuity of the germ-plasm," and for our present purposes we may take it as substantially correct, in principle if not in detail.

The simpler living organisms, which, like the amœba, consist each of only a single cell, are exempt from death, because in them the stream of protoplasm forms no overflows; it consists entirely of germ-plasm, and no differentiated bodies are formed, so that there is nothing to die, nothing which cannot go on reproducing itself indefinitely. Death is the penalty paid for a higher life, based upon a greater complexity of bodily mechanism.

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[1] From a citizens' lecture delivered at Edinburgh on September 8 during the meeting of the British Association.

In all that has been said hitherto, which must be already very familiar to most of you, we have been endeavouring to pave the way for the consideration of what is perhaps the most difficult and certainly the most vigorously discussed problem of biology—the problem of heredity. With regard to single-celled organisms such as the amœba, this problem scarcely exists. Division of the parent cell entails division of all that that cell possesses. The daughter-cells resemble the mother simply because they are that mother divided into two equal and similar parts.

With the higher organisms, each composed, perhaps, of many millions of cells, differentiated into many different kinds, and building up the most diverse tissues and organs, the situation is very different. In such a case how can a single, apparently undifferentiated, germ-cell, which has never taken part in the formation or in the activities of the body as a whole, and exhibits none of the features which characterise the tissue-cells—how can such a simple cell give rise by growth and multiplication to all the different kinds of cells, arranged in all the different tissues and organs, more or less exactly as in the parent?

The development of such an infinitely complex organism as, for example, the human body, from a microscopic egg-cell of apparently simple structure, seems, indeed, a kind of miracle, and the more closely we compare parent and child the more miraculous does the result appear, for not only is there a general resemblance in all essential features, but there is very frequently also a particular resemblance in minute peculiarities, such as the colour of the hair or eyes, the contour of the features, and so on.

It would be claiming far too much to say that we have as yet arrived at any complete explanation of heredity—this marvellously accurate reproduction in the child of the most minute details of bodily and mental organisation exhibited by the parent. But the explanation is, perhaps, after all, not quite so difficult as it seems at first sight. Let us go back to our loaves of bread and ask ourselves why one loaf resembles another. Why does the loaf that is baked on Tuesday resemble that which was baked in the same oven on Monday? The answer is obvious. One loaf resembles another because it is made from the same kind of dough and subjected to the same kind of treatment. If you take a different kind of dough, or subject the same dough to a different treatment, you will get a different result—and, as every housewife knows, there may be a vast difference between the loaves turned out by different bakers. The characters of the loaf clearly depend upon two sets of conditions: first, the nature of the dough itself, whether, for example, it is mixed with yeast or baking powder, water or milk, salt or sugar, and so on; and, secondly, the nature of the treatment to which the dough is subjected, the shape of the tins in which it is baked, the temperature of the oven, and so forth. If all the conditions are accurately repeated for successive batches of loaves, then the loaves of each batch will resemble those of the preceding batch.

We have in this respect a very close analogy with what takes place in heredity. The egg consists of a certain quantity of germ-plasm, and this germ-plasm has certain characteristic peculiarities of its own. In order that it may develop into an adult organism like the parent, it must be subjected to a certain treatment. In the case of a hen's egg undergoing incubation, or of the human fœtus developing in the womb of the mother, we may truthfully say that it has to be baked in an oven at a particular temperature. Only if all the conditions are accurately fulfilled will the egg develop into an organism resembling the parent, and it does so simply because the same causes must always produce the same effects. If you start with identical germ-plasm and expose it to identical conditions during its development, you must get an identical result. The child must resemble the parent. It is, indeed, easy to show by experiment that if you vary the conditions you may get either no result at all or a different one. Up to a certain point, however, the living organism has the power of counteracting accidental influences, and thereby maintaining its normality of structure. In other words, it is self-regulating, and seems to be always endeavouring to carry out the plan of structure characteristic of the species to which it belongs, so that, if this plan be disturbed, it will, within limits, be restored again by appropriate growth and readjustment. This power of adhering to a predetermined structural plan, in spite of disturbing influences, is one of the most distinctive attributes of living beings, and must on no account be lost sight of in considering the problem of heredity; but at the same time it is a power that is strictly limited.

A well-known American investigator, Prof. Stockard, has recently shown, in the case of various animals, how abnormalities can be produced by simply lowering the temperature during development. Some years ago the same observer obtained even more surprising results by the use of a simple chemical reagent. He exposed the eggs of the American sea-minnow (Fundulus) to the action of magnesium chloride, and found that the young fish tended to develop with a single eye in the middle of the head, instead of one on each side, though the modification was not in all cases complete. Thus we see that it is possible, by the application of a specific chemical stimulus to the egg, to bring about a profound and perfectly definite change in the structure of the organism, though we are still far from knowing why this should be the case.

We also know, from recent physiological research, that the growth of various organs in the animal body is normally controlled by infinitesimal quantities of chemical substances secreted by the ductless glands, such as the thyroid and the pituitary, and circulated in the blood, and that any deficiency or excess of these substances may produce abnormal results. The discovery of these hormones, as they have been termed by Prof. Starling, must have a profound influence on our ideas as to the mechanism of heredity. Their significance from this point of view was, I believe, first pointed out by Mr. J. T. Cunningham many years ago. It seems at least possible that chemical substances of a like nature may exist in the germ-cells and exercise a profound influence upon their development.

With this possibility in view, let us again examine the egg-cell at the very commencement of its development into a multicellular body, at the moment of its division into the first two daughter-cells, and let us concentrate our attention upon the nucleus, which always divides first. As it prepares itself for this important event a number of peculiar bodies called the chromosomes make their appearance, apparently by concentration of previously scattered granules of chromatin substance, so-called because of the way in which it can be stained by certain dyes. At the same time, a spindle-shaped arrangement of threads becomes manifest and the nuclear membrane disappears, so that there is no longer any sharp division between nucleus and cell-body. The chromosomes, often varying in shape and size amongst themselves, but definite and constant for each kind of organism, arrange themselves across the middle of the spindle. Then each splits into two, and one half moves away from the other and towards the corresponding end of the spindle. We have now two groups of daughter-chromosomes, and around each group a new nucleus is constituted. Then the protoplasm of the cell-body divides into two parts, and two complete cells are formed, each with its own nucleus.

The process is really far more complicated than this brief and inadequate description might lead you to suppose, but the essential feature seems always to be the behaviour of the chromosomes. It is very evident that the protoplasm of which these are composed must be of the utmost importance to the organism, and that it is necessary that it should be very accurately divided between the daughter-cells every time cell-division takes place. This phenomenon of mitosis, as it is termed, is of almost universal occurrence throughout the animal and vegetable kingdoms, not only in the early divisions of the egg-cell, but throughout the entire life of the organism, whenever cell-division takes place. It is clearly a contrivance by which a certain material substance—a particular kind of living protoplasm—is accurately distributed amongst the progeny of a dividing cell In other words, it is part of the mechanism of inheritance.

Let us now turn aside for a moment and glance very briefly at another and totally different line of evidence, leading to results which confirm and explain in a very remarkable manner those which we have already arrived at. I refer, of course, to the modern experiments in the breeding of plants and animals, undertaken under the influence of what is frequently termed the Mendelian school. It is utterly impossible to do justice to these wonderful experiments in the time at our disposal. I would point out, in the first place, however, that they have led quite independently to the striking conclusion that there must exist in the protoplasm of the germ-cells definite material entities—the so-called Mendelian factors—which are in some way or other responsible for the appearance in the adult organism of special features—the so-called unit characters—capable of being handed on from one generation to another by the process of heredity. Assuming them to be located in the chromosomes, the behaviour of these factors in inheritance, the permutations and combinations of unit characters which arise in cross-breeding, can be adequately explained by the behaviour of the chromosomes actually observed at certain critical periods of the life-cycle.

Take, for example, the colour of the human eye. If a certain factor, or combination of factors, alone be present in the germ-plasm, the eye will be blue or grey, but the addition of another factor may cause it to be brown, and the average results, as regards eye-colour, of mating pure blue-eyed and pure brown-eyed individuals can be confidently predicted. The occasional appearance of an extra thumb or finger upon the hand, which is well known to be a heritable character, transmitted with great regularity from parent to child, is again supposed to be due to the occurrence of a corresponding factor in the germ-plasm, and so on with a whole host of characters that have been carefully investigated by means of breeding experiments in recent years. It is important to note that these characters seem to bear no purposeful relation whatever to the well-being of the organism in which they occur. They are often extremely insignificant, and a large proportion of them must undoubtedly be regarded as abnormalities. It is a mere matter of chance whether they happen to be useful, neutral, or injurious.

We cannot attempt to discuss, or even state, however briefly, the evidence upon which this factorial hypothesis rests. Suffice it to say that it seems to afford the only possible explanation of the results of the long series of experiments inaugurated in Austria by the classical work of Mendel in the middle of the last century, carried on by Bateson, Punnett, Biffen, and others in England, and culminating in the brilliant investigations of the American school of geneticists under the leadership of Morgan.

The investigations of Prof. Morgan and his colleagues have gone so far as to demonstrate conclusively, albeit indirectly, not only that the Mendelian factors must be located in the chromosomes of the nucleus, but also that they must be arranged in each chromosome in a perfectly definite manner. These observers have even prepared maps of chromosomes showing the arrangement of the factors in linear series. It is surely one of the most remarkable achievements of modern science that we should be able to point to a particular spot in a particular chromosome of a microscopic germ-cell and say with confidence that there is something just there that is responsible for some particular character, such as the colour of the eye, in the adult organism.

As to the nature of the factors themselves, it seems not unreasonable to conclude that they must consist of definite chemical substances, or, perhaps better, of chemical modifications of living protoplasm, in the form of minute particles too small to be rendered visible by any means yet discovered, but capable of self-multiplication like other protoplasmic units.

We may further suppose that these factor-forming substances play a part in controlling the development of the organism comparable with that played by magnesium chloride in the case of the developing embryos of the sea-minnow, or by other chemical substances (hormones) in the normal adult animal. The complex mechanism of mitosis in the division of the cell-nucleus would then appear to be necessary in order to secure the proper distribution of factors throughout the growing body, so that each may reach the particular part that it is destined to influence.

It must be remembered that the occurrence of Mendelian phenomena in heredity depends entirely upon a much more fundamental phenomenon —that of sex—which gives the experimenter the opportunity of crossing two individuals differing as to one or more separately heritable characters, and of observing the numerical proportions of the offspring in which each of these characters makes its appearance.

The phenomenon of sex, as we all know, is a very great mystery, and introduces endless complications into life. Sexual differentiation appears to be nearly as old as the cell itself. The stream of life, almost since it first began to flow, has been a double stream, or, better, a network, in which male and female streamlets unite at more or less frequent intervals to form those temporary overflows which we call individuals. Each streamlet goes its own way for a time, and then joins and exchanges experiences, so to speak, with another. It is just this exchange of experiences that forms the basis of the Mendelian phenomena, and it is not merely the experiences of a single lifetime, but those of many generations that may be thus exchanged.

Perhaps, however, we are getting a little too metaphorical and had better consider in a rather more matter-of-fact manner what actually takes place in the sexual process. The essential feature of this process is always the same—the union of two germ-cells to form a single cell, although this fundamental act is greatly obscured in the higher plants and animals by the endless contrivances which have arisen in the course of evolution, and which serve the ultimate purpose of bringing the germ-cells together. In all the higher animals and plants these germ-cells are sharply differentiated into male and female, spermatozoa or sperm-cells and ova or egg-cells, and, with rare exceptions, the egg-cell cannot even begin to develop until it has united with, or, as we say, been fertilised by, a sperm-cell. This is very literally the union of two branches of the stream of life.

From the point of view of the theory of heredity, the most important thing about this union is the coming together of two sets of chromosomes—paternal and maternal—the one set coming with the spermatozoon from the male parent, and the other with the ovum from the female parent. The maternal and paternal chromosomes bring with them factors that have arisen in some unknown way, probably by chemical changes, in the two ancestral streams of protoplasm which unite in the fertilised egg. Apart altogether from the much-vexed question of the inheritance of "acquired" characters, which we cannot even touch upon this evening, these factors represent certain experiences which the stream of life has gathered on its journey.

Hence the new organism may exhibit certain characters derived from the father and others derived from the mother, a combination of paternal and maternal peculiarities, while the fundamental features of its organisation cannot be said to be derived from one parent more than from the other. It will resemble either parent just in so far as it starts life with the same potentialities, inherent in the germ-plasm as a whole and in its special factors, and just in so far as it develops under identical conditions. (We must not forget, though the point is not essential to our argument, that the germ-cells may perhaps contain other special factors besides those which have been located in the chromosomes.)

It is a curious fact, and one upon which our social reformers and preachers of equality would do well to reflect more seriously, that the characters, the potentialities for good or evil, of a living being should depend so much upon mere chance. A great deal can be done for the welfare of the individual by improving the conditions under which it lives, as every gardener knows, but nothing can altogether counteract the effects of hereditary tendencies. It is worth while to consider a little more fully how it comes about that chance plays such an important part.

With certain exceptions, which do not affect the general proposition, every cell of the living organism contains, as we have already seen, a double set of chromosomes, one set derived from the male and the other from the female parent. The duplication takes place at the time when the two germ-cells come together to form the fertilised egg, but it is counteracted again by reduction at another period of the life-cycle; otherwise the number of chromosomes in each cell would continue to increase in geometrical ratio from generation to generation, which is clearly impossible. It is at these two critical periods that chance steps in and prepares her surprises.

In the first place it seems to be purely a matter of chance what luck the germ-cells have in their mating, what particular ovum is fertilised by what particular spermatozoon, and, owing to the enormous numbers in which ova and spermatozoa are produced, the possibilities may be almost infinite. In the second place there are many alternative possibilities with regard to the particular factors which any given germ-cell, male or female, may contain. This depends upon which particular chromosomes happen to remain in the germ-cell after the double number has been halved again. In animals this halving takes place at the time when the germ-cells are ripening, shortly before they are ready to unite in the fertilised egg. The maternal and paternal chromosomes in each, differing as regards the factors they contain, pair off during the process of mitosis. The members of each pair then separate, and one of them alone remains in each mature germ-cell. Hence the germ-cells, even of the same individual, come to differ amongst themselves to a practically unlimited extent as regards their factorial constitution. The life of the individual is like a game of cards, in which a very great deal depends upon the shuffling of the pack, and the player has to do the best he can with the hand dealt out to him. He may make a hopeless failure of it, or a great success; but still the stream of life flows on, ever gathering and combining new experiences, ever forming itself into fleeting individualities and leaving them to perish on its banks as it passes on to fresh attempts at self-expression.

The interest of the Mendelian breeding experiments is so absorbing that it is little wonder if more fundamental aspects of the problem of heredity, to which we have alluded in the earlier part of our lecture, have been largely lost sight of in recent years, while the factorial hypothesis has been hailed by some extremists as the all-sufficient explanation of everything. The characters of the organism may indeed be modified by factors in the germ-plasm, just as the character of a loaf may be modified by putting caraway seeds into the dough; but the caraway seeds do not explain the loaf, and the Mendelian factors cannot explain the organism as a whole. There is doubtless a good deal of truth in the old saying that life is made up of trifles; but it is not the whole truth, and the body of a living organism cannot be regarded as merely the sum-total of its unit characters.

Whatever may be their significance from the point of view of the general theory of evolution and heredity, however, there can be but one opinion as to the immense practical importance of the Mendelian investigations. They have already led to the production of many valuable forms of life, more especially plants, that are to all intents and purposes new creations, although their value and novelty may depend merely upon the bringing together of desirable characters in new combinations and the elimination of undesirable features.

Nor are the possibilities of improvement by selective mating confined to our domesticated plants and animals. Hopes are entertained by many enthusiasts, banded together in the interests of what they have thought fit to term the science of Eugenics, of effecting vast improvements in the human race itself by the application of Mendelian principles. It does not seem likely, however, or even desirable, that men and women should ever consent to be guided in their choice of mates by purely utilitarian considerations.

There are many objections to any far-reaching schemes of this kind, but it does seem possible, when once the facts of heredity are generally known, that the exercise of an enlightened public opinion and individual choice may result in the elimination from the stream of human life of many heritable characteristics which it is very undesirable to perpetuate. In extreme cases, such as feeble-mindedness and certain forms of insanity, it may even be necessary for the community to protect itself by legislation against the criminal propagation of the unfit.

What is wanted, first and foremost, however, is education, and I trust that you will agree with me that it is education in biology—the science of life—to which we may most hopefully look for the physical and mental improvement of the human race. Men and women must learn to realise their responsibilities towards future generations from the biological point of view, and it is in this direction that the citizens of a great city like Edinburgh can best help, by generously supporting the cause of education and research as represented by your ancient and world-famed University.

Speech through the Æther.[1]

By SIR OLIVER LODGE, F.R.S.

AN intelligent deep-sea fish would disbelieve in water. It would be too uniform and omnipresent to make any impression on its senses. Near the surface it might encounter waves and currents, but to creatures thoroughly embedded in its depths water would make no display. Such is our own condition with regard to the æther of space. It eludes direct perception; its existence cannot be directly demonstrated; it has to be inferred.

The fish would probably also disbelieve in gravity, since it would not experience it, and some of the hyperintelligent among us, for quite another reason, seem to be following its example; but that is another story. Suffice it to say that direct sensation is but a poor clue to reality unless supplemented by a great deal of reasoning and indirect inferences. Our senses tell us only about

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[1] Abstract of a citizens' lecture of the British Association delivered at Edinburgh on September 6.